<u>What is claimed is</u>:

1. A method of measuring bone condition using ultrasound waves, comprising the steps of:

   a) transmitting a signal sequence of ultrasound waves for impingement on a bone being measured;

   b) arranging a detection transducer configuration for receiving a portion of the transmitted signal sequence of ultrasound waves after impingement on the bone being measured; and

   c) determining the degree of acoustic nonlinearity of the bone to estimate the material conditions of the bone.

2. The method of claim 1 used for detecting bone reduction and conditions related thereto.

3. The method of claim 1 used to estimate whether the bone is changing from a homogenous to a more heterogeneous structure.

4. The method of claim 1 wherein the nonlinearity of the bone is measured with harmonic frequency detection comprising the steps of:

   a) transmitting a sound pulse through the bone; and

   b) measuring the harmonic distortion.

5. The method of claim 4 wherein the second harmonic is sensed.

6. The method of claim 4 wherein a harmonic higher than the second harmonic is sensed.

7. The method of claim 4 wherein combinations of harmonics are sensed.

8. The method of claim 1 wherein the nonlinearity of the bone is measured with nonlinear frequency mixing detection comprising the steps of:

a) transmitting two frequencies through the bone;

b) receiving the transmitted signals; and

c) measuring the sum and/or difference frequencies in the received signal.

9. The method of claim 8 wherein the two frequencies transmitted are transmitted by two separate transducers.

10. The method of claim 8 wherein the two frequencies are transmitted by exciting one transducer with both frequencies.

11. The method claim 9 wherein the transmitted signals are received by one of the transducers that transmitted a frequency.

12. The method of claim 9 wherein the transmitted signals are received by a third transducer.

13. The method of claim 10 wherein the transmitted signals are received by the transducer that transmitted the frequencies.

14. The method of claim 10 wherein the transmitted signals are received by a second transducer.

15. The method of claim 1 wherein the nonlinearity of the bone is measured with a combination of harmonic detection and nonlinear frequency mixing detection.

16. The method of claim 15 further comprising the steps of:

a) transmitting a plurality of signals at different frequencies through the bone;

b) receiving a portion of the transmitted signals;

c) measuring the sum and/or difference frequencies of a first transmit frequency combined with the harmonics of a second transmit frequency.

17. The method of claim 15 further comprising the steps of:

a) transmitting two frequencies through the bone;

b) receiving the transmitted signals;

c) measuring the sum and/or difference frequencies of the harmonics of the transmit frequencies.

18. The method of claim 1 used in conjunction with other measurement techniques.

19. The method of claim 18 where the other measurement technique measures at least one of reflection of sound and scatter of sound.

20. The method of claim 18 where the other measurement technique measures attenuation of sound.

21. The method of claim 18 where the other measurement technique measures speed of sound.

22. The method of claim 1 used in conjunction with estimates for elastic properties.

23. The method of claim 1 used in conjunction with measurements of shape.

24. The method of claim 1 used in conjunction with measurements of geometrical dimensions.

25. A method for diagnosing osteoporosis comprising the steps of:

a) transmitting a signal sequence of ultrasound waves for impingement on a bone being measured;

b) arranging a detection transducer configuration for receiving a portion of the transmitted signal sequence of ultrasound waves after impingement on the bone being measured; and

c) measuring the degree of acoustic nonlinearity of the bone to estimate the material conditions of the bone indicative of the onset of osteoporosis.

26. The method of claim 25 further comprising the step of assigning the measured bone portion a bone strength index.

27. The method of claim 26 further comprising the step of repeatedly comparing sequential time spaced measurements of the same bone structure to identify onset or susceptibility to bone disease.

28. The method of claim 25 in which the step of measuring the degree of acoustic nonlinearity of the bone comprises:

a) transmission to achieve a two frequency mixing by transmitting two frequencies f_1 and f_2; and

b) receipt of f_1 and f_2 at the difference and/or sum frequencies f_1-f_2 and f_1+f_2.

29. The method of claim 25 in which the step of measuring the degree of acoustic nonlinearity of the bone comprises:

a) transmission of an amplitude modulated signal by transmitting a signal $p=(1+A\sin 2\pi f_m t)\sin 2\pi f_0 t$; and

b) receiving the signal at a modulation frequency f_m and a selected second or higher harmonic of that frequency.

30. The method of claim 25 in which the step of measuring the degree of acoustic nonlinearity of the bone comprises:

a) transmission of signals comprising one high imaging frequency f_i and one low pumping frequency f_p; and

b) receiving the signals at sum and/or difference frequencies f_i-f_p and f_i+f_p.

31. The method of claim 25 in which the step of measuring the degree of acoustic nonlinearity of the bone comprises:

a) transmission of a signal comprising one transmit frequency f_0; and

b) receiving the signal at a harmonic of the transmit frequency.

32. A method of measuring bone strength comprising the steps of:

a) measuring the shear wave velocity (c_s);

b) estimating the Lamé coefficient shear modulus (μ) of the bone by use of the formula:

$$C_s = \sqrt{\frac{\mu}{\rho}}$$ and

c) assigning a bone strength index of measure based on the estimate of shear modulus.

33. The method of claim 32 further comprising the additional step of measuring bone strength by measuring the degree of nonlinearity of the bone to estimate the material conditions of the bone.

34. The method of claim 32 used in conjunction with other measurement techniques.

35. The method of claim 34 where the other measurement technique measures reflection of sound.

36. The method of claim 34 where the other measurement technique measures scatter of sound.

37. The method of claim 34 where the other measurement technique measures attenuation of sound.

38. The method of claim 34 where the other measurement technique measures speed of sound.

39. The method of claim 34 used in conjunction with estimates for elastic properties.

40. The method of claim 34 used in conjunction with measurements of shape.

41. The method of claim 34 used in conjunction with measurements of geometrical dimensions.

42. A method for diagnosing osteoporosis comprising the steps of:

a) measuring the pressure wave velocity through a patient's bone;

b) measuring the shear wave velocity through a patient's bone;

c) calculating the ratio of shear wave velocity to the pressure wave velocity

to determine whether the bone is degraded.

43. The method of claim 42 further including calculating the speed of sound in the bone by transmitting ultrasonic waves using a transmitter placed on the surface of a patient's skin, through the tissue to the bone at a predetermined angle, receiving ultrasonic waves refracted from the bone at a receiver positioned on the surface of a patient's skin a known distance from the transmitter, and measuring the time of the first arrival of refracted ultrasonic wave at the receiver.

44. A device for measuring bone density comprising a means for measuring the shear wave velocity through a patient's bone.

45. The device of claim 44 wherein a first transducer transmits a wave into the patient's bone and a second transducer receives the wave.

46. The device of claim 45 wherein the first and second transducers are the same transducer.

47. The device of claim 44 further comprising a means for measuring the pressure wave velocity through a patient's bone.

48. A system for measuring bone density by measuring the shear wave velocity through a patient's bone.

49. A method of measuring bone density comprising the step of measuring the phase velocity as a function of frequency.

50. The method of claim 49 further comprising the step of measuring the frequency dependant attenuation.

51. The method of claim 49 further comprising the steps of

a) measuring the degree of nonlinearity of the bone to estimate the material conditions of the bone; and

b) measuring the shear wave velocity and estimating the shear modulus (μ) of the bone.

52. The method of claim 49 used in conjunction with other measurement techniques.

53. The method of claim 52 where the other measurement technique measures reflection of sound.

54. The method of claim 52 where the other measurement technique measures scatter of sound.

55. The method of claim 52 where the other measurement technique measures attenuation of sound.

56. The method of claim 52 where the other measurement technique measures speed of sound.

57. The method of claim 49 used in conjunction with estimates for elastic properties.

58. The method of claim 49 used in conjunction with measurements of shape.

59. The method of claim 49 used in conjunction with measurements of geometrical dimensions.

60. A device for measuring bone density comprising a means for measuring the phase velocity as a function of frequency.

61. A system for measuring bone density comprising a means for measuring the phase velocity as a function of frequency.

62. A method for diagnosing osteoporosis comprising the steps of:

1) placing a transmitter of ultrasonic waves on a predetermined area on the surface of a patient's skin;

2) placing a receiver of ultrasonic waves on an area on the surface of the patient's skin a known distance from the transmitter;

3) transmitting ultrasonic waves through the tissue to the bone at a predetermined angle;

4) measuring the time of the arrival of the first ultrasonic wave by the receiver; and

5) calculating the speed of sound in the bone using the time of arrival of the first ultrasonic wave.

63. A system for diagnosing osteoporosis comprising:

1) a transmitter configured for transmitting ultrasonic waves onto a predetermined area on the surface of a patient's skin and through the tissue to the bone so as to create a surface wave at a bone-tissue interface region that is measurable by a receiver of the ultrasonic surface wave;

2) at least one receiver of ultrasonic waves on an area on the surface of the patient's skin a known distance from the transmitter; and

3) analysis circuitry for measuring the surface wave velocity and translating the measured velocity into an indicator of bone health status.

64. The system of claim 63 in which the transmitter is configured so that the tissue-bone interface is in the acoustic near field of the transmitter.

65. The system of claim 63 comprising means for selectively either vertically polarizing or horizontally polarizing the surface wave that is generated.